Simulation of Interference Effects from UWB Sources on a Narrowband Digital Transmission System

Idnin Pasya, Atsushi Tomiki, and Takehiko Kobayashi

Tokyo Denki University, Department of Information and Telecommunication Engineering, Wireless Systems Laboratory
2-2-1201 Kanda Nishiki-cho, Chiyoda-ku, Tokyo 101-8457 Japan.
idnin@grace.c.dendai.ac.jp Tel & Fax: +81-3-5230-3839

Abstract–*This paper studies the interference effects from 4 types of ultra wide band (UWB) sources on a narrowband π/4-shift differential quadrature phase keying (DQPSK) transmission system by simulation. The culprit UWB sources were: multi-band orthogonal frequency-division multiple-access (MB-OFDM), direct-sequence code-division multiple-access (DS-CDMA), DS spread spectrum UWB (DS-SS UWB), and additive white Gaussian noise (AWGN). The MB-OFDM and DS-CDMA were modeled based on the proposal specifications in the IEEE.802.15.3a to standardize high-speed wireless personal area networks. Average bit error rates (BER) degradation of the victim system was evaluated in the presence of the UWB signals as a source of interference. We propose a modified equivalent baseband system to accelerate the simulation speed. In the proposed system, the victim system was generated in the passband domain, while the UWB signals were generated at the equivalent baseband domain to lower the sampling rate of the simulation. It was found that the interference effects of the UWB signals were almost equivalent to that of an AWGN. However, since the MB-OFDM marks spectral peaks at every 3.2 MHz in the frequency spectrum, it severely degraded the BER performance in the victim system. The amplitude probability distributions of the UWB signals were dependant upon the frequencies that enters the victim's receivers.*

Keywords–*Ultra wide band, MB-OFDM, DS-CDMA, interference, equivalent baseband, amplitude probability distribution*

I. INTRODUCTION

UWB technologies have attracted considerable interest due to its potential to generate high data rates of communication. UWB systems are expected to coexist with conventional narrowband radio systems in the frequency domain. For this reason, the evaluation of interference effects from UWB systems to existing radio systems are essential for the commercialization of UWB technologies. The regulating authorities in many countries have authorized the emission limit mask for UWB communication systems to protect existing radio services. However, doubts and contradiction in the standardization of these regulations are limiting the realization of UWB systems in the near future.

Regarding coexisting problems, the studies concerning electromagnetic compatibility of UWB systems with other narrowband transmission are strongly encouraged by the Federal Communications Commission and other regulating authorities. Initial studies show that UWB signals closely resembles noise to narrowband receivers. Tesi *at al.* have evaluated the performance of an OFDM receiver under the presence of an impulse radio as an interference source using computer simulations [1], and pointed out that although UWB signals are not Gaussian signals, their interference effects on narrowband systems are equivalent to that of Gaussian noise. Supporting this result, the bit error rates degradation of a digital wireless transmission system caused by impulse radio and DS-SS UWB have been experimentally evaluated [2].

The present work studies the interference effects from 4 typical UWB signals on a narrowband transmission system. The victim system used was the π/4-shift DQPSK transmission system, which is the most commonly used modulation scheme in mobile communications nowadays. The simulated UWB signals are MB-OFDM [3] and DS-CDMA [4], which was modeled based on IEEE.802.15WPAN (TG3a)'s standard proposal specifications, DS-SS UWB [5] and AWGN.

This paper also investigates the statistical characteristics of the UWB signals by calculating their amplitude probability distribution (APD), which is useful for identifying the signals behavior in the victim receiver. Most receivers are designed to operate in bands with Gaussian noise, which is characterized by the average noise power statistics alone. However, the amplitude statistics of UWB signals are dependent upon their specifications and the frequency entering the band limited filter of the victim receiver. This induces the author to include the APD measurement of the UWB signals in this research.

The remainder of this paper is organized as follows. In Section II, we introduce the simulation model employed in this work. In Section III, we explain the simulated 4 types of UWB sources; The APD characteristics of UWB signals will be discussed in Section IV. In Section V, computer simulation results are presented in terms of BER performance of the victim system. Finally, we draw conclusions in the last section of this paper.

II. SIMULATION MODEL

Figure 1 depicts the simulation model used in this study, which was implemented using SPW® (Signal Processing Worksystem), a software designed for signal processing and numerical simulations. We define the victim system as a π/4-shift DQPSK transmission scheme, assuming an ideal modulation at 400 kHz data rates, within a 300 kHz bandwidth. The modulated signal was shifted to the RF band with a carrier wave, and UWB sources are added as a source of interference. Next, thermal noise was added to the transmission signal before being demodulated at the victim receiver. Note that the indoor multi-path fading was not a subject in this study. Finally the average bit error rates were calculated while verifying the desired-to-undesired signal power ratio (*D/U*), where *D* is the transmission

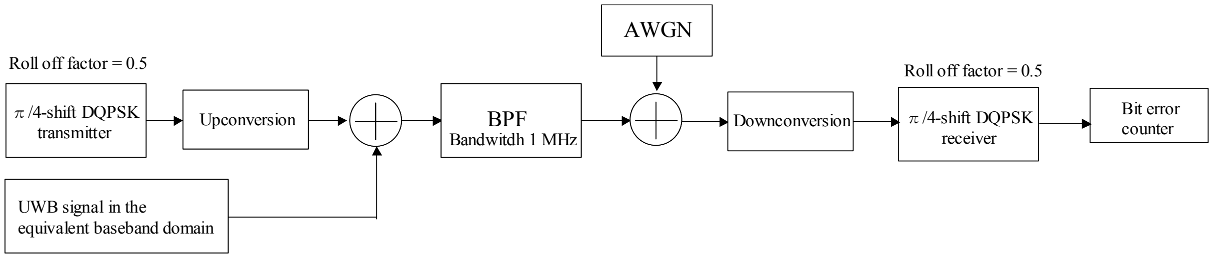

Fig. 1. Simulation diagram.

signal's average power and U represents the power of the interference signal's average power occupying the same frequency domain.

In real environments, UWB systems would be occupying a high frequency bandwidth (generally 3.1 GHz to 10.6 GHz). However, to generate such high frequency signals, we would need a significantly high sampling rate, which must be twice the highest frequency according to the sampling theory. Thus, the simulation period will be significantly longer. Therefore, we propose a modified equivalent baseband system to speed up the simulation. The modified equivalent baseband system requires lower sampling frequency because the UWB signals are generated in the baseband domain. Figure 2 illustrates the spectral relation between the culprit UWB system and the victim narrowband system, whose center frequencies are f_c and f_v, respectively, in the real radio frequency domain and the modified equivalent baseband domain. The UWB signals have wide frequency spectrum, thus allowing them to overlay with the victim system in the frequency domain, although being generated in baseband. The victim system was shifted from f_v to $f_v - f_c$ in order to tune the center frequency to specific frequencies of the UWB signal.

III. UWB Sources Used in This Study

This section briefly introduces the 4 types of UWB sources used in this study. As mentioned above, the UWB sources generate complex baseband signals in the equivalent baseband domain. The MB-OFDM and DS-CDMA use the parameters that are being proposed for the IEEE.802.15WPAN (TG3a) standards. The waveforms in the time domain and the spectra in the frequency domain of these signals are shown in Figs. 3, and 4.

A. MB-OFDM

The MB-OFDM is a multi-carrier transmission scheme, where the data bits are mapped to 128 sub-carriers, which are allocated at every 4.125 MHz. The UWB spectrum is divided into several 528 MHz bands, and frequency hopping within these bands to support multiple accesses. In this study, only one sub-band was used, which means that the frequency hopping was not applied. Figure 2 shows the temporal structure of the OFDM frame. The total length of an OFDM symbol is 312.5 ns, where 242.2 ns of them is the data length, 60.6 ns are the zero-padded prefix, and the other 9.2 ns are the guard interval.

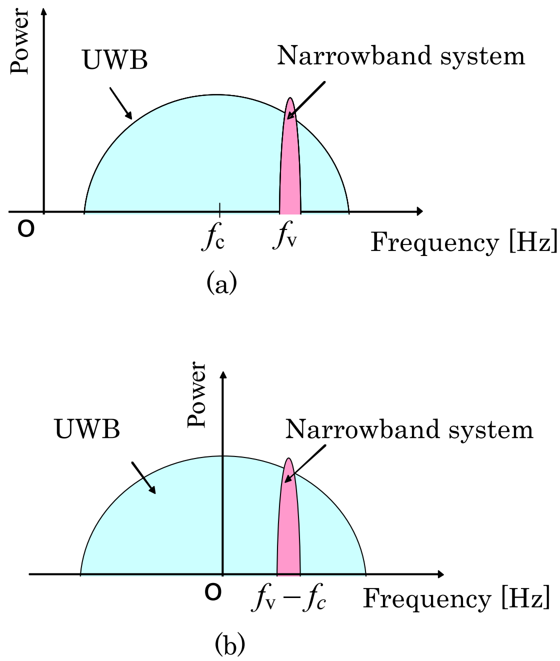

Fig. 2. Frequency spectra of the culprit UWB system and the victim narrowband system in (a) the real radio frequency, and (b) the modified equivalent baseband domain.

The power spectrum of the MB-OFDM is represented in Fig. 4. (a). We have found that spectrum peaks appear at every 3.2 MHz due to zero padding of the OFDM symbols. These peaks are about 10 dB above the average total power. The interference effects from the MB-OFDM at these frequencies needed to be evaluated, and so did the statistical characteristics of the signal.

B. DS-CDMA

Concerning the DS-CDMA signal used in this study, ternary codes are assigned to the modulated symbols from the lookup table as defined in the proposal [3]. The modulation scheme used was binary phase shift keying (BPSK). The pulse was then filtered with a pulse-shaping filter, before being transmitted to the victim's channel. The frequency spectrum was spread to around 800 MHz of bandwidth. The length of each pulse is 9 ns, and the pulse repetition frequency (PRF) is 110 Mb/s.

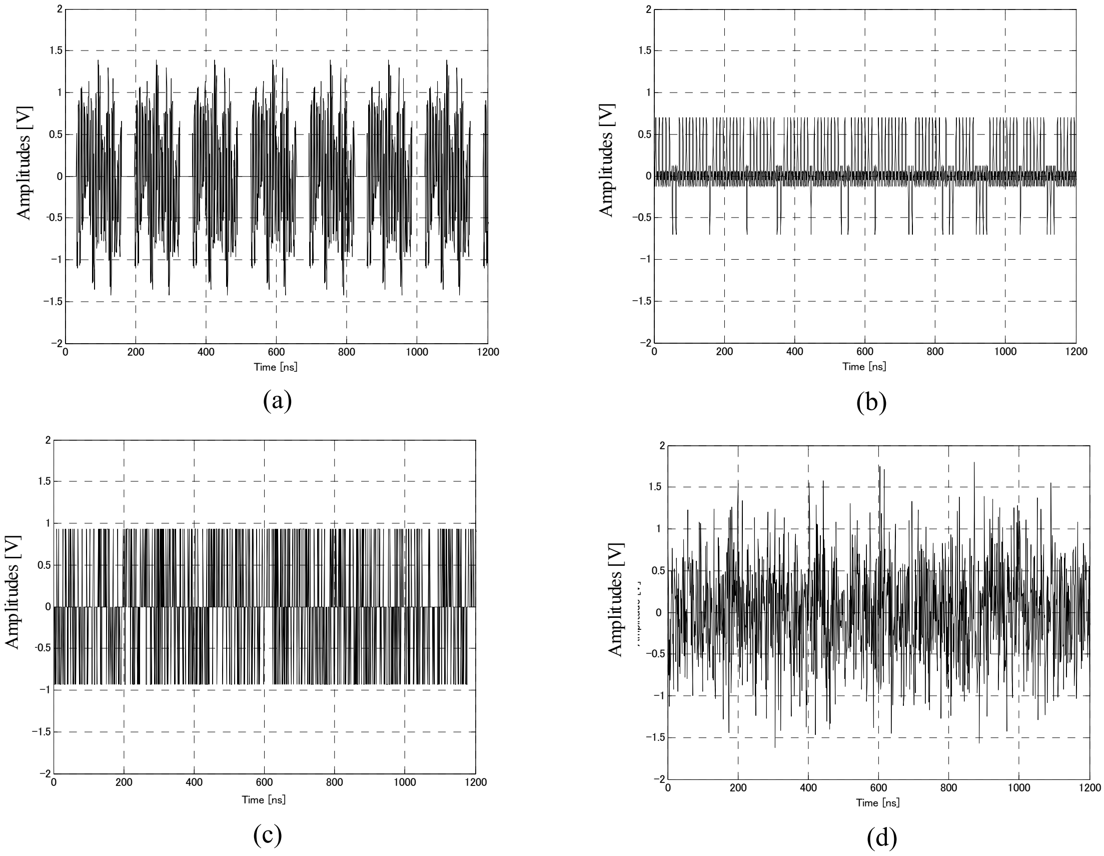

Fig. 3. The wave forms of the culprit UWB signals in the time domain: (a) MB-OFDM, (b) DS-CDMA, (c) DS-SS UWB, and (d) AWGN.

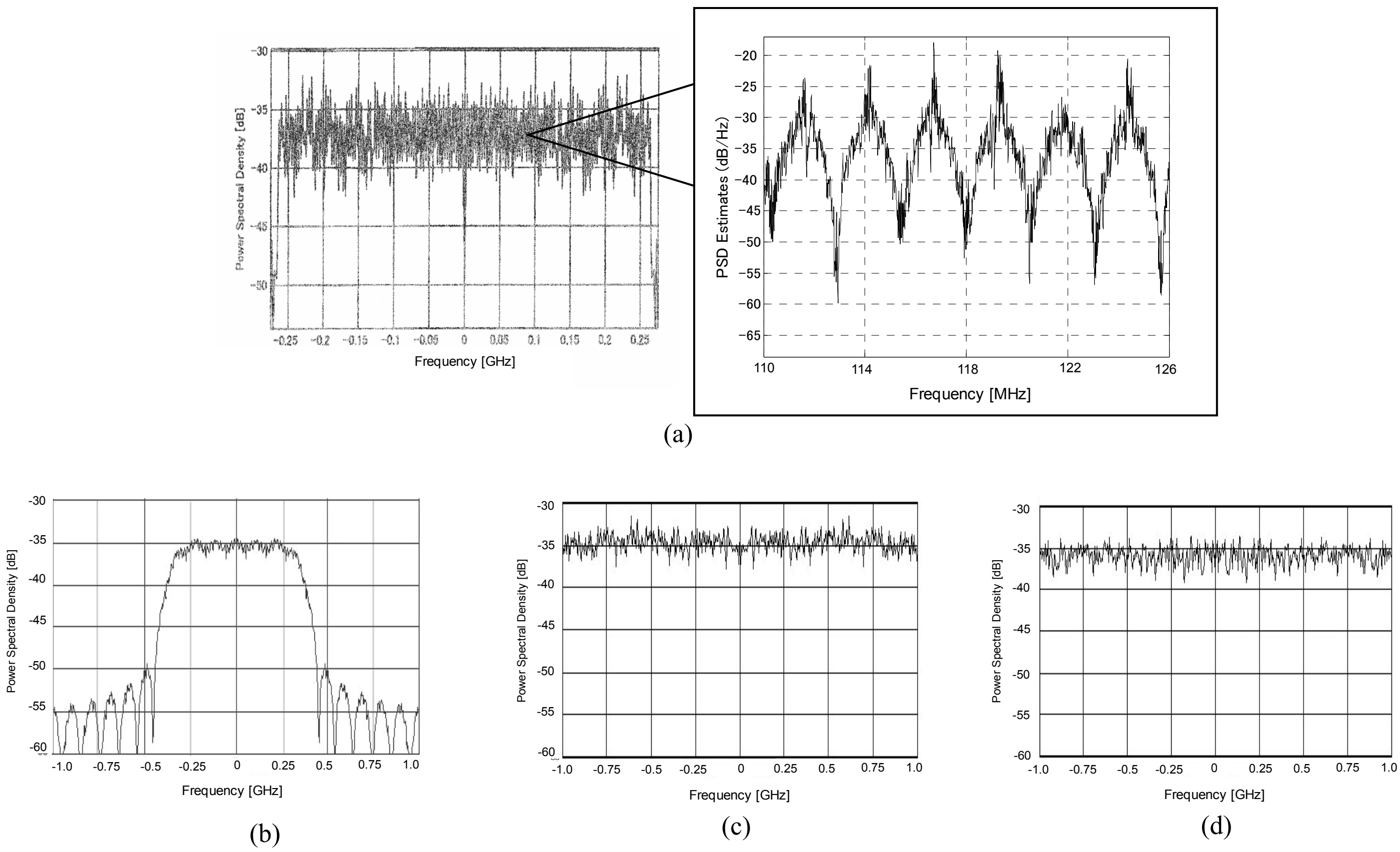

Fig. 4. The power spectra of the culprit UWB signals: (a) MB-OFDM, (b) DS-CDMA, (c) DS-SS UWB, and (d) AWGN.

The DS-CDMA power spectral density is shown in Fig. 4. (b). Due to the spread spectrum technique applied, the comb spectral lines at multiples of the PRF are suppressed.

C. DS-SS UWB

We modeled a DS-SS UWB signal similar to the signal developed in own laboratory using actual circuits, described in [5]. Basically, the DS-SS UWB uses a 15-step PN sequence generator with a chip rate of 2 GHz to spread a stream of BPSK modulated data bits. We can see in Fig. 4. (c) that the frequency spectrum yielded a 2 GHz of bandwidth. The signal had a spectrum much wider than the conventional version of the conventional DS-SS transmission system.

D. AWGN

The AWGN signal was implemented by generating Gaussian-distributed random sequence at a sampling rate of 2 GHz sampling frequency to obtain a wide spectrum signal. Figure 4 (d) illustrates the frequency spectrum of the signal.

IV. Statistical Properties of the UWB Signals

The APD describes a statistical property of a signal's amplitudes, which may be used to predict the particular signal's behavior in the victim receiver. A passband signal is usually expressed by

$$s(t) = A(t)\cos(2\pi f_c + \theta(t)) \quad (1)$$

where $A(t)$ is the baseband amplitude, $\theta(t)$ is the baseband phase, and the f_c is the center frequency. Having 0 Hz as the center frequency, complex baseband signal can be defined by the following equation:

$$s(t) = A(t)e^{j\theta(t)}. \quad (2)$$

Here, the signals' envelopes variables *A*, were converted to decibels, defined by the function.

$$y(t) = 20\log_{10}(A). \quad (3)$$

The discrete PDF expresses the *probability* that a random variable *.A*. will have a realization equal to *.ai*:

$$p(a_i) = P(A = a_i). \quad (4)$$

where *P*() is the probability of its argument. PDF values are positive and the area under a PDF is equal to 1.0. Next, we integrated the PDF of the signals to obtain the discrete CDF. The probability exceeding ordinate is determined by subtracting the value from 1.0. The calculated APD is plotted on a Rayleigh graph. Figure 5 shows the calculated APD of the signals implemented in this study, where

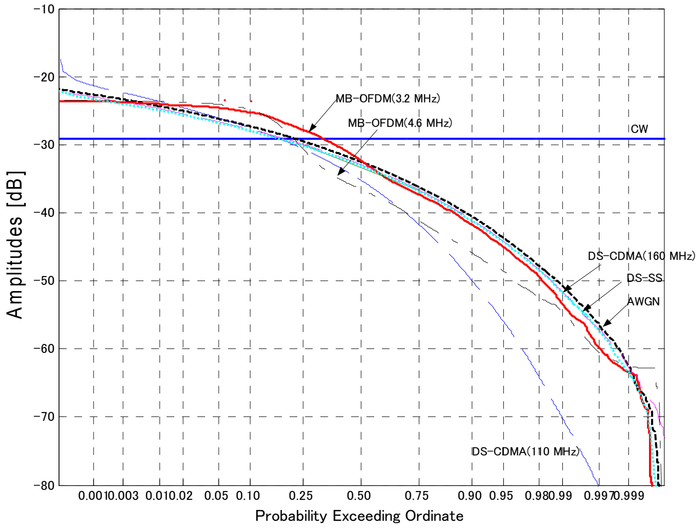

Fig. 5. Calculated APD of signals implemented in this study.

observations were made at the victim system's receiver, which is 300 kHz of bandwidth. The APD of a CW signal is also shown for reference.

It was verified that the APD of the DS-SS UWB signal approximates that of an AWGN, because of the randomized data streams. The DS-CDMA also indicates similar APD characteristics. However, at the PRF frequencies, the APD is non-Gaussian. On the other hand, the MB-OFDM clearly has non-gaussian APD where high amplitudes mark high probability. At the spectral peaks at 3.2 MHz intervals, the amplitudes of the MB-OFDM signal exceed the AWGN at the median value.

V. Simulation Results and Analysis

Results from the computer simulations are represented in Figure 6 (a) to (f). The average BER was calculated while varying the D/U from 5 dB to 15 dB. It was found that the BER degrades from the theoretical value in every case. For most cases, the BER degrades significantly when the D/U is around 5 dB, producing floor characteristics of the BER. This means that the UWB signals cause immense interferences when the power is relatively high.

Figures 6 (a) and (b) verified the BER performance of the AWGN and the DS-SS UWB. It can be seen that the interference effects of DS-SS UWB are similar to that of an AWGN of the same power. This corresponds to its APD, which closely overlays a Gaussian distribution. The BER performance of the DS-CDMA's case is represented in Figures 6 (b) to (c), where the center frequency of the victim system is tuned to the PRF frequencies (100 MHz) and other frequencies (160 MHz). We found that the interference effects of both cases are identical to the AWGN's case. Although the APD of the DS-CDMA at the PRF frequencies are slightly different from the AWGN, the comb spectral line effects are seem to be suppressed due to the spread spreading technique applied.

Figures 6 (e) to (f) shows the BER degradation in the case where MB-OFDM was implemented as a source of interference. When the center frequency of the victim's

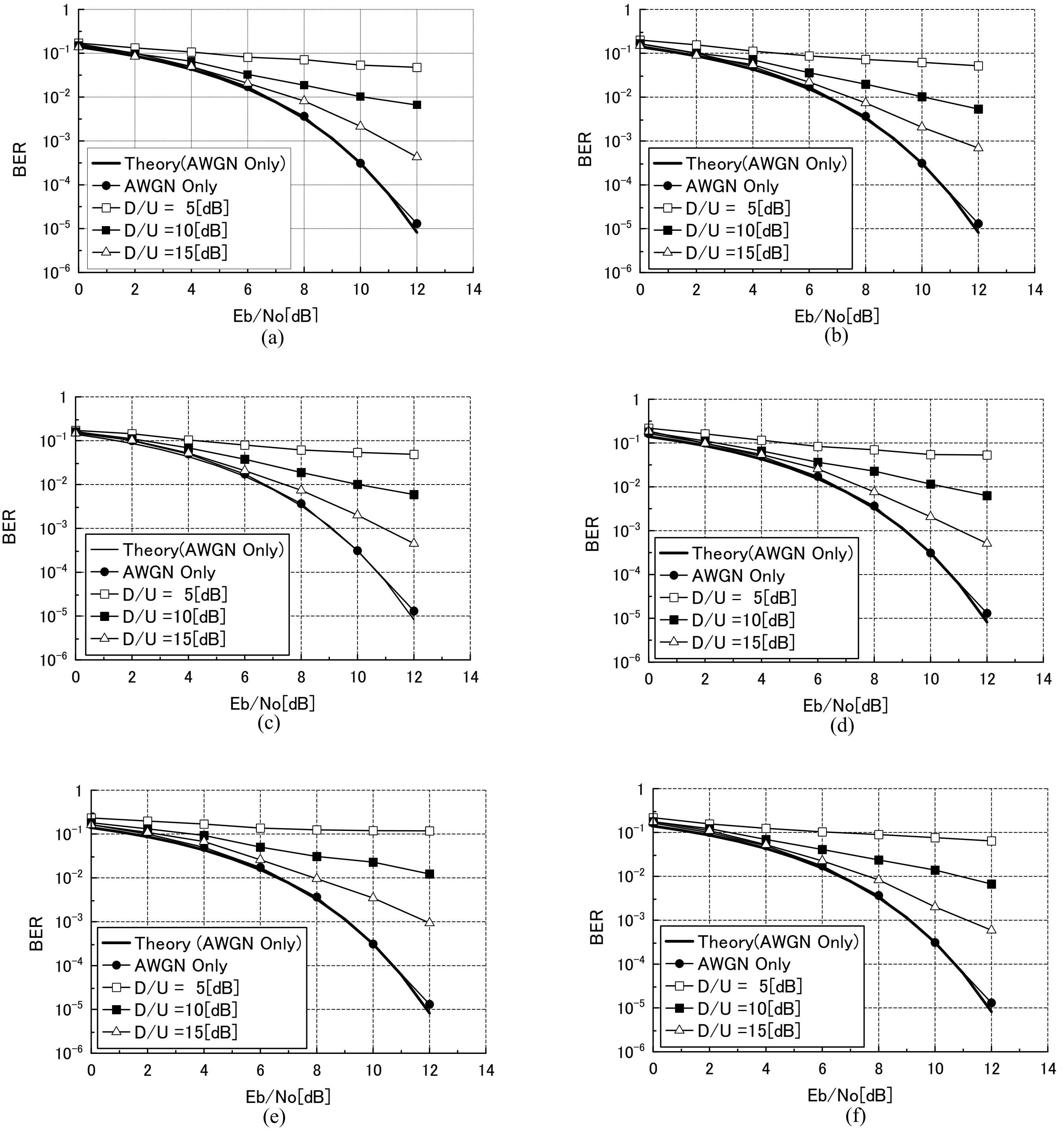

Fig. 6. The BER performance of the victim's receiver: (a) AWGN, (b) DS-SS UWB, (c) DS-CDMA (100 MHz from center frequency), (d) DS-CDMA (160MHz from center frequency), (e) MB-OFDM (3.2 MHz from center frequency), and (f) MB-OFDM (4.6 MHz from center frequency).

receiver was tuned to spectral peaks of the MB-OFDM signal, the BER degradation was 2 dB higher than the AWGN case. This is attributable to the high amplitudes with high probability above the median value, according to the APD. In other frequencies, the interference effects are approximately equal to that of an AWGN. Even though the BER performance at the spectral peaks was worst, it was only a 2 dB difference. Thus, it can be assumed that the BER is nearly the same.

To summarize, the interference effects from the UWB signals to DQPSK transmission system approximated that of an AWGN, with slight difference in certain cases. In this evaluation, the interference level was verified as a function of D/U, where the U was calculated as the power of the UWB signal occupying the same frequency region – not the average total power. However, in practice, if it is assumed that the interference source is positioned at a certain distance from the receiver's antenna, the interference signal's power is defined by the average total power. This means that the spectral peaks of the MB-OFDM will surely degrade the BER severely. The calculated BER performance of the DS-SS UWB case agrees considerably with the results shown in [2], where actual measurements of the average bit error rates were done using an ideal software receiver. This shows that the results of this simulation are accurate.

VII. CONCLUSIONS

The interference effects from 4 types of UWB signals to π/4-shift DQPSK transmission system were evaluated. In the bandwidth where spectral peaks of the MB-OFDM signal were located, the BER degradation was 2 dB worse than any other cases. Nevertheless, it can be concluded that the interference effect from UWB sources approximates the AWGN. However, the MB-OFDM showed spectral peaks at every 3.2 MHz that would degrade the BER further. We have also investigated the statistical characteristics of UWB by calculating their APD. The UWB signals characteristics are dependant upon the frequencies in the victim's receiver.

Our future work will include the evaluation of the interference effects of UWB sources on a narrowband system under a multi-path environment, and also simulations considering non-linear aspects of actual hardware circuits to closely model the measurements in practice.

ACKNOWLEDGEMENTS

Part of this study has been funded by the Strategic Information and Communications R&D Promotion Scheme under the Ministry of Telecommunication of Japan and the Research Institute of Science and Technology (grant no. 2Q240), Tokyo Denki University. The author would also like to express special thanks to CoWare Co. for providing the simulation tool for this study.

References

[1] R. Tesi, M. Condreanu, and I. Opperman, "Inteference effects of UWB transmission in OFDM communication systems," in *Int. Workshop on Ultra Wide Band Systems*, Oulu, Finland, June 2003.

[2] A. Tomiki, T. Ogawa, A. Fukuda, N. Terada., and T. Kobayashi, "Evaluation of interference from impulse-radio and direct-sequence-UWB sources to 2-GHz digital radio transmission," in *IEEE Internat. Symp. on Electromag. Compat.*, TH-P-I1.4, Istanbul, Turkey, May 2003.

[3] A. Batra *et al.*, "Texas Instruments et. al., IEEE 802.15.3aUpdated MB-OFDM Proposal Specification (03/268r3)," Nov. 2003

[4] M. Wellborn, "DS-UWB Physical Layer Submission to 802.15 Task Group 3a (04/137r)," Mar. 2004.

[5] A. Tomiki, T. Ogawa, and T.Kobayashi, "Experimental Evaluation of Interference from UWB Sources to a 5-GHz Narrowband Digital Wireless Transmission System," in *IEEE Conf. On Ultra Wide Band Systems and Technologies, Reston, VA, USA, Nov 2003.*